Plant diversity and generation of ecosystem services at the landscape scale: expert knowledge assessment

Quijas, Sandra ; Jackson, Louise E ; Maass, Manuel ; Schmid, Bernhard ; Raffaelli, David ; Balvanera, Patricia

Abstract: 1. In spite of the increasing amount of experimental evidence on the importance of plant species richness for ecosystem functioning at local scales, its role on the generation of ecosystem services at scales relevant for management is still largely unknown. To foster research on this topic, we assessed expert knowledge on the role of plant diversity in the generation of services at the landscape scale. 2. We developed a survey that included three levels of organization and seven components of plant diversity; four provisioning, six regulating and four cultural services; as well as three resources and three conditions among key abiotic factors that are likely to provide a contribution to service generation equalling that of plant diversity. Eighty experts in areas of biodiversity, ecosystem functioning and services answered the survey. 3. The experts identified species diversity within a community and diversity of communities within the landscape as the most important levels of organization for service generation, both with positive effects. Composition and number of species were considered to be the most relevant components of plant diversity, the latter with a positive effect on services. Water availability was identified as the most important abiotic resource. 4. Our results suggest different approaches to management for sustaining the generation of services at the landscape scale. Provisioning services were perceived as largely influenced by abiotic resources and less so (although positively) by plant diversity. Regulating services were expected to strongly depend on both plant diversity and abiotic factors. A particularly strong positive effect of plant diversity was expected for the generation of cultural services. Some variation in answers could be attributed to expert background. 5. Synthesis and applications. The expert survey generated detailed information and new hypotheses on the relationship between plant diversity and services at the landscape scale. Future research is needed to test these hypotheses, yet the areas of agreement identified in this study can be used immediately, with caution, as synthetic expert knowledge at spatial scales that are relevant for management, to guide technological and policy interventions ensuring the maintenance of biodiversity and ecosystem service delivery.

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Title:

Plant diversity and generation of ecosystem services at the landscape scale: expert knowledge assessment

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Summary

1. In spite of the increasing amount of experimental evidence on the importance of plant species richness for ecosystem functioning at local scales, its role on the generation of ecosystem services at scales relevant for management is still largely unknown. To foster research on this topic, we assessed expert knowledge on the role of plant diversity in the generation of services at the landscape scale.

2. We developed a survey that included three levels of organization and seven components of plant diversity, four provisioning, six regulating and four cultural services, as well as three resources and three conditions among key abiotic factors that are likely to contribute as much as plant diversity to service generation. Eighty experts in areas of biodiversity, ecosystem functioning and services answered the survey.

3. The experts identified species diversity within a community and diversity of communities within the landscape as the most important levels of organization for service generation, both with positive effects. Composition and number of species were considered to be the most relevant components of plant diversity, the latter with a positive effect on services. Water availability was identified as the most important abiotic resource.

4. Our results suggest different approaches to management for sustaining the generation of services at the landscape scale. Provisioning services were perceived as largely influenced by abiotic resources and less so (though positively) by plant diversity. Regulating services were expected to strongly depend on both plant diversity and abiotic factors. A particularly strong positive effect of plant diversity was expected for the generation of cultural services. Some variation in answers could be attributed to expert background.

5. *Synthesis and applications.* The expert survey allowed for the generation 50 of detailed information and new hypotheses on the relationship between plant diversity and services at the landscape scale. Future research is needed to test these hypotheses, yet in the meantime areas of agreement can be used with caution as synthetic expert knowledge to guide technological and policy interventions to ensure the maintenance of biodiversity and ecosystem service delivery.

Keywords

Abiotic resources and conditions, components of diversity, cultural services, diversity-direction of effect hypotheses, levels of organization of diversity, provisioning services, regulating services, survey.

Introduction

The study of biodiversity´s influence on ecosystem functioning has developed over the past 20 years into an important area of ecological research (Naeem *et al*. 2009). Results from this research clearly point to the critical role that biodiversity plays for the generation of ecosystem services and thus human well-being. To date, qualitative (Diaz *et al*. 2006) and quantitative (Balvanera *et al*. 2006; Worm *et al*. 2006; Quijas, Schmid & Balvanera 2010) syntheses derived from experimental manipulation of biodiversity and ecosystem functioning have shown a consistently positive effect of diversity in the generation of ecosystem services for a range of organisms, habitats and services.

Yet these syntheses are limited because they mostly refer to the outcomes of small-scale experiments, are confined to a limited range of ecosystem services, deal mostly with species richness and not with other components of diversity, do not address the role played by abiotic factors in such relationships, and potentially generate equivocal messages as a result of confounding effects directions from a range of ecosystem service providers and habitats. Experiments manipulating diversity have largely been developed at local scales (<10 ha; Balvanera *et al*. 2006) and yet ecosystems are managed and services delivered at landscape (10–1,000 ha) to regional scales (>1, 000 ha; Kremen 2005; Duffy 2009). The syntheses are also limited by their focus on only a few types of ecosystem services, mainly regulating and provisioning ones (Balvanera *et al*. 2006; Worm *et al*. 2006; Quijas, Schmid & Balvanera 2010), cultural services being poorly described (Worm *et al*. 2006).

In addition, studies in this area only focus on the species level of organization, and on richness as the main measure of species diversity (Balvanera *et al*. 2006), thus ignoring the relative contributions of other biodiversity attributes, such as level of organization (e.g. genotype, populations, communities), species evenness, species composition, and functional diversity (Kremen 2005; Diaz *et al*. 2007; Luck *et al*. 2009). Furthermore, the relative importance of abiotic factors with respect to diversity on ecosystem functioning or services has seldom been analyzed (Diaz *et al*. 2007). Finally, a wide variety of organisms that may function as ecosystem service providers (Luck *et al*. 2009) have simultaneously been considered in syntheses (Balvanera *et al*. 2006; Worm *et al*. 2006), yet, their individual contribution to ecosystem services is likely to be different (Luck *et al*. 2009; Quijas, Schmid & Balvanera 2010).

Thus future research on the relationship between biodiversity, functioning and services should embrace a broader range of spatial scales, biodiversity components, and ecosystem services; include the relative role of abiotic factors with respect to biodiversity; and dissect the role of specific ecosystem service providers to be applied into management decisions. In particular, focusing on terrestrial plants as ecosystem service provider can be quite useful given their fundamental role in ecosystem functioning, their direct contribution to the generation of many ecosystem services, and the not surprising majority of studies that have focused on the relationships between their diversity and ecosystem functioning (Quijas, Schmid & Balvanera 2010; Cardinale *et al*. 2011).

Given the lack of information described above, one approach is to synthesize present understanding, define key knowledge gaps and stimulate further hypothesis testing through expert assessments (Schläpfer, Schmid & Seidl 1999). Expert elicitation, a technique used to synthesize opinions of experts, has been in use for several decades in disciplines of economics, sociology, political science, social psychology, and public opinion research (de Vaus 2002), and more recently it is also being incorporated in studies of ecology and conservation biology (Halpern *et al*. 2007; Donlan *et al*. 2010). Expert judgment is not intended to be a substitute for scientific research, but to define the current knowledge that may not otherwise be easily accessible, illustrate the current sense of expert knowledge, reveal areas of greater or lesser agreement and help drive future applied research (Halpern *et al*. 2007; Donlan *et al*. 2010). An initial survey of expert knowledge aimed at understanding the relationship between biodiversity and its components on ecosystem processes, and the generation of ecosystem services, was conducted by Schläpfer, Schmid & Seidl (1999). Yet, in the last decade, biodiversity and ecosystem functioning research has added realism including other components of diversity (Symstad 2000; Wilsey and Potvin 2000), increasing the spatial scale of analysis of processes related to ecosystem services, using more realistic extinction scenarios (Zavaleta & Hulvey 2004), simultaneously measuring multiple functions (Hector & Bagchi 2007) and incorporating natural (Fukami & Wardle 2005) and anthropogenic gradients of disturbance (Zavaleta *et al*. 2003). A new expert assessment would allow us to synthesize perceptions and advances relevant for managing both biodiversity and ecosystem services to ensure their maintenance.

In this paper, we use an expert assessment approach to synthesize current understanding of how plant diversity relates to the generation of 14 ecosystem services at the landscape spatial scale. We focus on: *i*) direction of effect and relative importance of different levels of organization of plant diversity in the generation of ecosystem services, *ii*) direction of effect and relative importance of different components of plant diversity in the generation of ecosystem services, and *iii*) importance of plant diversity relative to the abiotic resources and conditions that can have direct effects on the generation of ecosystem services. We also assessed potential for biases in results given by the background of participating experts.

Materials and methods

Spatial scale

Understanding the spatial scales at which ecosystems are managed and services are delivered to people will be essential to developing landscape-level conservation and management plans (Kremen 2005). For that reason, this assessment is focused at the landscape scale, defined here as areas ranging from 10 to 1,000 ha (0.01 to 10 km2; 24,710 to 2,471,000 acres). We used analogies to help experts visualize theses scales (e.g. the Principality of Monaco or Niagara Falls has an area of 100 ha, whilst the city of Beverly Hills has an area of 1,000 ha).

Components of the survey

A summary of the approach that we used in this survey is shown in Fig. 1. We divided the survey into five sections. The first and second sections evaluated understanding about the direction of effect and relative importance of the levels of organization of plant diversity on service generation. The third and fourth sections evaluated understanding about the direction of effects and relative importance of components of plant diversity on service generation. The fifth section evaluated understanding about the relative importance of resources and conditions. We considered four provisioning services, six regulating services and four cultural services. We did not include supporting services, as we considered them to be ecosystem processes that indirectly benefit societies by supporting one of the other three types of services. We identified three levels of organization relevant for the generation of services and six components of plant diversity. We considered three resources and three conditions that are likely to modify both plant diversity and service generation. A glossary with all definitions can be found in Appendix S1 in Supporting Information.

Identification of the relationship between diversity and services

The direction of effect of plant diversity on the generation of ecosystem services was assessed using five types of relations: *i*) the more diversity, the more service (+), *ii*) the more diversity, the less service (–), *iii*) there is a diversity effect on the service, but it is not possible to determine its direction or the direction is unknown (1), *iv*) no influence of diversity on the generation of the service (0), *v*) unknown whether there is an influence of plant diversity for the generation of the service (?). For example, "higher genetic diversity provides better pest regulation" and thus the more diversity there is, the more service (+); or "a higher number of species does not influence soil fertility," thus there is no influence of diversity on the generation of service (0).

The relative importance of plant diversity, as well as that of abiotic resources and conditions, on the generation of services was assessed using four categories: (1) of little importance, (2) of intermediate importance, (3) very important and (?) of unknown importance.

Building the survey

Two drafts of the survey were developed before reaching the final version used here (for details see Appendix S2). In final version we included background questions for evaluating potential bias due to expert perspectives on final results; the questions related to subject of expertise (e.g. population ecology, management), type of work (e.g. basic research, decision maker), type of organization (e.g. institute, environments NGO`s), years working with plant diversity and ecosystem processes and/or services they know, and the focus ecosystems where they work (e.g. tropical rain forest, grassland).

Expert selection

We defined as experts those individuals who had carried out observational and experimental research on the links between plant diversity and ecosystem functioning or ecosystem services at different spatial scales. We used the list of contributors to the Millennium Ecosystem Assessment contributors (MA 2005) and a list of researchers working in these areas suggested by the co-authors of this work as a source of candidates. We identified 408 experts, but we could not find the email addresses of 64 of them. The survey was sent by email to 344 experts between July 2007 and March 2008; reminder emails were sent up to two times. A total of 56 experts responded to the email, but did not participate in the survey, mainly due to time constraints (17), or due to self-stated lack of expertise on plant diversity and ecosystem services (38). A total of 80 experts (23%) responded to the survey. Respondents worked in over 27 countries and 14 types of ecosystems (more details see Appendix S3).

Analysis

We registered the frequencies of the different types of responses and then addressed the following questions:

i. Do experts tend to recognize a particular type of effect or relative importance of plant diversity in the generation of ecosystem services when considering all levels of organization or all components of diversity?

ii. What is the direction of effect and relative importance of the different levels of organization and components of plant diversity most commonly mentioned by experts when considering all ecosystem services?

iii. What is the relative importance of abiotic resources and conditions with respect to plant diversity most frequently mentioned when considering all ecosystem services?

iv. What is the type of effect and relative importance of the different levels of organization of plant diversity most frequently recognized by experts for the generation of each of the ecosystem services?

v. What is the type of effect and relative importance of the different components of plant diversity most frequently recognized by experts for the generation of each of the ecosystem services?

vi. What is the relative importance of abiotic resources and conditions with respect to plant diversity most frequently recognized for the generation of each of the ecosystem services?

vii. How does the background of experts explain the differences in how frequently they chose different types of effects and what relative importance they assigned to plant diversity and abiotic resources and conditions for the generation of services?

To test for differences in answer probabilities we assumed as a null model that all answers to a question would be equally likely. Thus, the five possible answers (–, 1, +, 0, ?) about the direction and significance of biodiversity effects or the four possible answers (1,2,3,?) about the relative importance of plant diversity and abiotic resources and conditions on the generation of services were all considered equally likely. While this may not always have been the best null model, we had no other information to develop more specific null models. Significant deviation from the expected equal answer probabilities were detected with generalized linear and chi-square tests (Sokal & Rohlf 1995) (for details see Appendix S4). We used Bonferroni corrections to account for the large numbers of test performed (360 hypotheses tested; critical P<0.00014 for individual tests, corresponding to an overall significance level of P<0.05). Although sequential Bonferroni adjustment can increase the probability of rejecting a null hypothesis when it would be inappropriate to do so (Moran 2003), in our case it did not greatly reduce the number of significanses and help to clarify inconsistencies between answers for each individual question. We further used adjusted residuals (residuals divided by their variance) as an a-posteriori test for identifying particular frequencies responsible for the significant chi-square values, and to explore whether particular answer frequencies were larger (or smaller) than expected from the null model (Everitt 1992).

We assessed biases caused by different backgrounds of experts on frequencies of responses about the links between plant diversity and ecosystem services. We used χ^2 tests to test for independence of answers with respect to expert characteristics (e.g. five types of relations vs. type of ecosystem). We used a Bonferroni correction on the critical P values as a-priori test for the numbers of test performed (25 hypotheses tested; critical P<0.002). Adjusted residuals were also used to identify particular frequencies that differed from the null model (calculated using the same Bonferroni correction).

Results

We found that most experts recognized a positive effect of plant diversity on the generation of ecosystem services when all levels of organization (Fig. 2a) and all components of diversity (Fig. 2b) were pooled together. However, there was no consensus on the relative importance of plant diversity in the generation of services. We found large discrepancies between experts, with opinions for importance varying between little and very important often considered for levels of organization (χ^2 = 8.1, P=0.01, df = 2), most components of plant diversity were most frequently considered to be of little importance (χ^2 = 22.8, P<0.0001, df = 2).

Direction of effects and relative importance of levels of organization of plant diversity

Genetic diversity within species, species diversity within a community, and the diversity of the communities in the landscape were consistently identified as having a positive effect on ecosystem service generation (genetic χ^2 = 601.4, P<0.05, df = 4; species χ^2 = 1980.1, P<0.05, df = 4; community χ^2 = 1609.7, P<0.05, df = 4; Table 1). However, the relative importance changed between levels of organization, because plant diversity at the species (χ^2 = 594.6, P<0.05, df = 3) and communities in the landscape (χ^2 = 474.4, P<0.05, df = 3) were most often considered as very important, while diversity at the genetic (χ^2 = 1110.57, P<0.05, df = 3) level of organization was most frequently recognized as of little importance.

Direction of effects and relative importance of components of plant diversity

Direction of effect of components of plant diversity on service generation was considered positive and the relative importance differed between components (Table 1). Clear positive effects were attributed to number of species (χ^2 = 1575.7, P<0.05, df = 4), species evenness (χ^2 = 395, P<0.05, df = 4), functional diversity (χ^2 = 661, P<0.05, df = 4), spatial turnover (χ^2 = 411.5, P<0.05, df = 4) and structural diversity (χ^2 = 1044.8, P<0.05, df = 4). While number of species was consistently considered as very important (χ^2 = 272, P<0.05, df = 3), plant species composition and structural diversity were thought to be of intermediate importance to very important (composition χ^2 = 531, P<0.05, df = 3; structural χ^2 = 227.7, P<0.05, df = 3). Other components of plant diversity including species evenness, functional diversity and spatial turnover were rated as less important for the generation of services.

Importance of plant diversity relative to abiotic resources and conditions

Plant diversity together with water availability were most frequently considered by experts as the most important factors for the generation of ecosystem services (plant diversity $\chi^2 = 79.7$, $P<0.05$, df = 3; water $\chi^2 = 37.1$, $P<0.05$, df = 3; Table 2). Disturbance intensity was identified to be of only intermediate importance; soil type and position on the landscape were rated of intermediate to little importance. Energy and nutrient availability were recorded as the least important for the generation of services.

Direction of effect and relative importance of levels of organization of plant diversity on the generation of different types of ecosystem services

Species diversity within a community was consistently regarded by experts as the most important level of organization with positive effects for the case of provisioning services (Table 3). Genetic diversity was recognized as the least important for these services, with either positive effects or non-effects most commonly reported.

Species diversity within a community and the diversity of the communities in the landscape were most often considered of intermediate importance to very important for the generation of regulating services; in contrast, genetic diversity was considered the least important. Positive effects of species diversity and diversity of the communities were indicated for all regulating services. Direction of effect of genetic diversity on the generation of regulating services was most often considered to be either positive or no-existent (Table 3).

Plant diversity at the species and community levels was consistently considered by experts as of intermediate importance to very important for the generation of cultural services, and positive effects were the most frequent in both cases. Genetic diversity was recognized as the least important for cultural services, with no-effect most commonly reported (Table 3).

Direction of effect and relative importance of components of plant diversity on the generation of different types of ecosystem services

Species composition, i.e. specific combination of the species or presence/absence of particular species within a plant community, was the only diversity component that was most frequently identified by experts as very important for the case of provisioning services (Table 4); most of the other components of plant diversity were expected to have positive effects of little importance on provisioning services.

For regulating services, species composition and number of species were considered to be the most important components of plant diversity; positive effects were reported for the generation of soil fertility, regulation of plant pests and invasion resistance (Table 4). The functional diversity was considered important with for the regulation of the response of the ecosystem to extreme events. Positive effects of functional diversity and structural diversity were identified for water related services and for climate regulation and air quality.

Species composition was most often considered as the most important component of plant diversity for the generation of various cultural services. Structural diversity was identified as important for scenic beauty and number of species for traditional use. Most of the components of plant diversity were expected to have positive effects on the generation of all cultural services, except functional diversity that was considered to have no effects on these services (Table 4).

Relative importance of abiotic resources and conditions on the generation of different types of ecosystem services

The relative importance of abiotic resources and conditions differed markedly among types of services (Table 5). Water, energy and nutrient availability were considered most important for most provisioning services. Plant diversity was most important for three regulating services, water availability for one, while nutrient availability, soil type position within the landscape for one and disturbance intensity for two. In the case of cultural services, only water availability was identified as important for the generation of recreation and tourism services; in all other cases only plant diversity was considered important.

Biases given by expert background on assessment of plant diversity and ecosystem service generation

Some biases associated with background of expert were found on the frequencies for direction of effects and relative importance of plant diversity on service generation. When pooling together all levels of organization of plant diversity we found an effect of type of organization (χ^2 = 54.6, P<0.05, df= 12) and of focus ecosystem where scientists worked (χ^2 = 205.5, P<0.05, df= 52): experts working for NGO`s indicated that plant diversity had no effects on ecosystem services more frequently than expected from a null model, while those working in agroecosystems more frequently chose an unknown influence. Relative importance of plant biodiversity on ecosystem service provision was influenced by the focus ecosystem (χ^2 = 104.5, P<0.05, df= 39); experts working in agroecosystems and successional forest chose more frequently an unknown relative importance of plant diversity. When, pooling together all components of plant diversity, we found that subject of expertise (χ^2 = 347, P<0.05, df= 24), type of organization (χ^2 = 203.3, P<0.05, df= 12), years of experience (χ^2 = 87.8, P<0.05, df= 12) and focus ecosystem (χ^2 = 516.6, P<0.05, df= 52) influenced expert assessments:

plant and community ecologist reported more frequently identified a positive relationship between plant diversity and service generation, while managers, individuals working for NGOs and governmental agencies, experts with less experience (<10 years) and those focusing on agroecosystems and successional forests tended to report more no-effects and unknown relationships. Answers on relative importance of plant diversity were biased by subject of expertise (χ^2 = 120.3, P<0.05, df= 18) and focus ecosystem (χ^2 = 103.8, P<0.05, df= 39), reflect that frequency of unknown importance of plant diversity on services generation were higher than expected for those studying population ecology and agroecosystems; respondents working in agroecosystems more frequently reported unknown importance of plant diversity relative to abiotic resources and conditions on service generation (χ^2 = 72.2, P<0.05, df= 39). For more details see Appendix S5.

Discussion

Synthesis knowledge gained at landscape scales

Our work synthesized perceptions of experts on the relationships between plant diversity and ecosystem services at the landscape scale. The assessment showed that when all the services were pooled together a positive effect of plant diversity on service provision was consistently found. The generality of this positive effect is consistent with previous publications on the contribution of diversity to a stable supply of ecosystem services as spatial and temporal variability increases, which typically occurs over larger areas, such as the ones addressed here (Loreau, Mouquet & Gonzalez 2003; Diaz *et al.* 2006).

Yet there was no consensus on the relative importance of plant diversity on service provision. The relative importance given to diversity changed among services.

This lack of consensus may derive from different underlying mechanisms, the effect of context or just the scarcity of information in this topic.

Consistent with previous qualitative reviews (Kremen 2005; Diaz *et al*. 2006), experts consistently identified diversity of species within a community and diversity of communities within a landscape as the most important levels of organization for service generation. In both cases a positive relationship was suggested. Composition and number of species were considered to be the most relevant components of plant diversity. Yet, experts interviewed saw little importance for the role played by genetic diversity in the provision of services, despite the growing evidence of its role in generating useful plant products such as food, fodder and fiber (Jackson, Pascual & Hodgkin 2007), regulation of plant pests (Schweitzer *et al*. 2005) and resistance to plant invasion (Barberi *et al*. 2010) at the landscape scale. Our results reflected consistency only for what appear to be the more widely known levels of organization and components of plant diversity among ecologists (Hooper *et al*. 2005).

Patterns of plant diversity effects on types of ecosystem services

Positive relationships between plant diversity and generation of provisioning services at the landscape scale were consistently indicated, thus suggesting that experts expected clear local synergy between the maintenance of wildland biodiversity and obtaining provisioning services to satisfy human needs. Yet, the role played by species evenness and functional diversity as components of plant diversity for generating provisioning services (e.g. food, fodder, fiber and biofuel intensive production) was not recognized, despite accumulating scientific evidence that indicates that agrobiodiversity is extremely important for indigenous, small-scale farms that provide much of the world's food supply (Perfecto & Vandermeer 2010). In addition, growing recognition in literature exists for the importance of functional diversity on regulating (e.g. maintenance of soil fertility, landslide and avalanche risk) and cultural services (e.g. cultural heritage, land stewardship) at the landscape scale (Diaz *et al*. 2007; Lavorel *et al*. 2011).

In the case of regulating services, there are two groups of these services: one for which consistently positive effects of plant diversity were recognized and those with no consistency. The first group corresponds to services that have been widely studied at local scale and somewhat at landscape scale (e.g. soil fertility, plant pest, resistance to plant invasion; Landis *et al*. 2005; Vacher *et al*. 2008). For the other group, experts showed no consistency both regarding the direction of effects of diversity components as well as their relative importance for these services (e.g. water amount, quality and temporal variability), even though there is a wide literature exploring links between plant diversity and regulating services, or at least the processes that underpin them (Appendix S6). This suggests either a lack of understanding of the ecological processes associated to service generation, a lack of clear patterns emerging from such literature, or a lack of awareness of a larger set of biophysical literature outside the field of ecology.

Finally, a positive effect of plant diversity on the generation of cultural services was consistently recognized by experts. This is surprising given ecologists' limited understanding of these services (Chan *et al*.2011); yet, the consensus may reflect the well-known connections between cultural diversity and biodiversity that is widely known in the fields of economic botany, indigenous use of native plants, and anthropology.

Relative importance of abiotic resources and conditions on service generation

The relative importance of abiotic resources and conditions with respect to plant diversity on service provision at the landscape scale varied greatly among types of services. Provisioning services were perceived to be largely influenced by abiotic resources and little (though positively) by plant diversity; regulating services were thought to depend on both plant diversity and abiotic resources and conditions; abiotic factors were not considered relevant for cultural services. These results differ from previous syntheses (Loreau *et al*. 2001; Hooper *et al*. 2005; Balvanera *et al*. 2006) and may indicate that experts assumed greater influence of abiotic factors among than within sites, thus increasing their relative importance at the larger landscape scale (Loreau, Mouquet & Gonzalez 2003). Further research is needed to fully understand how abiotic resources and conditions are related to biodiversity and service provision as spatial and temporal scale increase.

Limitations of assessment: representativeness and biases of experts and data analyses

The assessment was aimed at identifying people who have carried out research on plant diversity and ecosystem services, and is thus not based on a random sample of people. The percentage of experts that responded to the survey (23%) is similar to that reported by other expert opinion studies on biodiversity (Schläpfer, Schmid & Seidl 1999; Halpern *et al*. 2007). The majority of experts worked in community and ecosystem ecology at research institutes, and had more than 10 years of experience with plant diversity or ecosystem processes/services when they answered the survey. Analyzing the characteristics that described the experts in this study (see Appendix S3) showed that they have thought deeply about the subject and were thus likely to provide authoritative estimates on plant diversity and ecosystem services. Furthermore, their understanding of the topic very likely included experience beyond their particular research publications.

Some biases emerged from expert background. As explained above, experts working in management, in NGOs or governmental agencies, those focusing on transformed ecosystem (e.g. cropland, pasture, exotic pine and eucalyptus plantations, irrigated rice fields, secondary tropical wet forest, savanna transition) and those with less experience (<10years) tended to more frequently report no influence of plant diversity on service generation (nature of effects and relative importance). This suggests that experts dealing with real-world conditions are either more skeptical of emerging research findings derived from the experimental literature, are less aware of them, or that information relevant to their needs is lacking; for instance, a rigorous meta-analysis of the direction of effect of diversity in agricultural environments has only been published recently (Letourneau *et al*. 2011).

The future will usher in new questions on biodiversity and ecosystem services and allow access to new empirical data or additional expert opinion. Given the broad reach of the internet, web-based expert opinion surveys are a strategic way to aggregate information that can help set priorities for conservation and management action plans and related research (Donlan *et al*. 2010). Priority setting for maintenance of biodiversity and management of ecosystem services at the landscape scale cannot wait for exhaustive empirical research. Instead, survey instruments can be easily replicable and quickly updated to include new sources of information, control for expert bias and refine the results from direction of effect and relative importance of plant diversity on services generation.

The statistical methods used here were very useful to address the questions posed. The Bonferroni adjustments may have increased the probability of not rejecting some null hypothesis when it would been appropriate to do so (Moran 2003). Yet, changes in the observed patterns with this correction were only found for the most complex assessments of the effects on individual ecosystem services (Tables 4 and 5) and helped us to more clearly identify the major inconsistencies among experts (Appendix S..?. The use of generalized mixed effect models with individual experts as random factor and expert background categories as fixed contrasts within this random factor would have been an alternative analysis possibility (de Vaus 2002). Due to the complexity of the design we used the described chi-square tests without random factors instead.

Future research: questions main and management implications

The results of our expert knowledge assessment can be translated into different hypotheses on the relationships between plant diversity and services generation that could further be tested. Future research should focus more on the relative importance of plant diversity on services, rather than the direction of its effects that are better known. Plant genetic diversity effects seem to differ between ecosystem services types. Also, the relative role of plant diversity on service provision may change across types of ecosystems. The role of components of plant diversity such as functional diversity may change across different types of regulating and cultural services. Finally, exploring the relative role of plant diversity with respect to that of abiotic resources and conditions for different types of ecosystem services is particularly relevant for management. This set of hypotheses should help to identify unexamined research questions that would lead to a novel approach to observational and experimental studies for the foundation of rigorous and science-based evidence for the management, conservation and sustainable use of biodiversity and ecosystem services at the landscape scale.

Our approach and results can be used in a number of ways to inform and aid management decisions. This expert assessment can identify themes of agreement that may be used with caution as a synthesis of expert knowledge to guide technological and policy interventions. It also highlights themes for which closer communication between scientists and managers is needed.

Conclusions

Our survey revealed which attributes of plant diversity in the eyes of our experts are most likely to have effects on the generation of services at landscape scales. Expert assessment identified diversity of species within a community and diversity of communities within a landscape as the most important levels of organization for service generation with positive effects; the same can be said for composition and number of species among the components of plant diversity. Water availability was perceived to be the most important abiotic resource for service generation at the landscape scale; but this was not the case for all services. Provisioning services were thought to be largely influenced by abiotic resources and little (though positively) by plant diversity. Sustaining the generation of regulating services was expected to depend on both plant diversity and abiotic resources and conditions. A very important positive effect was attributed to plant diversity for the generation of cultural services. Most experts do know and seem to trust the results of observational and experimental research that plant diversity increases ecosystem functions; this pattern was true even when those doing more real-world work that were among the most skeptical about the existence of such links. Key areas of future research to guide ecosystem management include the role of plant genetic diversity and that of abiotic factors on landscape scales. Overall, the experts interviewed agree that at the landscape scale the importance of maintaining plant diversity is crucial if the management goal is to ensure and sustain provision of ecosystem services for human well-being.

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Supporting Information

Additional Supporting Information may be found in the online version of this article

Appendix S1. Glossary of terms used in this survey.

Appendix S2. Phases of building the survey assessment.

Appendix S3. Background experts that answered the survey on the relationship between plant diversity and ecosystem services.

Appendix S4. Direction of effect and relative importance of levels of organization, components of plant diversity, abiotic resources and conditions.

Appendix S5. Biases associated with background experts that were found on the frequencies for direction of effects and relative importance of plant diversity on service generation.

Appendix S6. Publications found in a search of the ISI Web of Knowledge about relationship between plant diversity and ecosystem services.

Table 1. Expert assessment of direction of effect and relative importance of levels of organization and components of plant diversity on the generation of ecosystem services. Cells with a square indicate levels of organization and components that were significantly more frequently mentioned than would be expected from a null model of equal frequencies of all answers, both for effects and relative importance; *P*<0.00014 (■); cells with no square indicate no significantly different frequencies from those expected from the null model. (--) is used to show that the direction of species composition effect on the generation of services could not be assessed (see text for details).

Attributes of plant diversity		Effects					Relative importance			
		–	1	+	0	?	1	2	3	?
Levels of organization	**Genetic** diversity within species			■	■		■			
	Species diversity within a community			■				■	■	
	Diversity of **communities** within in the landscape			■					■	
Components	Number of species			■					■	
	Species evenness			■			■			
	Species composition	--	--	--	--	--		■	■	
	Functional diversity			■			■			
	Spatial turnover			■			■			
	Structural diversity			■				■	■	

Symbols and numbers: Effects: –) the more diversity the less service; 1) there is a diversity effect on the service, but it is not possible to determine its direction or the direction is unknown; +) the more diversity the more service; 0) no influence of diversity on the generation of the services; ?) unknown whether there is an influence of plant diversity for the generation of services. Relative importance: 1) little importance; 2) intermediate importance; 3) very important; ?) unknown importance.

Table 2. Expert assessment on the relative importance of plant diversity with respect to that of resources and conditions for the generation of ecosystem services. Presentation of cells as Table 1; p<0.00014 (■).

		Relative importance			
		1	2	3	?
	Plant diversity			■	
Resources	Water availability			■	
	Energy availability	■			
	Nutrient availability	■			
Conditions	Soil type	■	■		
	Position within the landscape	■	■		
	Disturbance intensity		■		

Symbols and numbers: presentation as in Table 1.

Table 3. Expert assessment of direction of effect and relative importance of levels of organization of plant diversity on the generation of ecosystem services. Presentation of cells as Table 1; p<0.00014 (■).

Type	Services	Direction of effect															Relative importance											
		Genetic					Species					Community					Genetic				Species				Community			
		–	1	+	0	?	–	1	+	0	?	–	1	+	0	?	1	2	3	?	1	2	3	?	1	2	3	?
Provisioning	Food, fodder, fiber and biofuel intensive production			■					■					■			■						■		■			
	Timber production								■								■						■		■			
	Firewood production				■				■								■						■					
	Diverse products			■					■					■			■						■					
Regulating	Soil fertility								■					■			■						■					
	Plant pests			■					■					■									■					
	Resistance to plant invasion			■					■					■			■						■					
	Response of the ecosystem to extreme events			■					■					■			■					■					■	
	Water availability				■				■					■			■					■					■	
	Climate regulation and air quality				■				■					■			■					■					■	
Cultural	Scenic beauty				■				■					■			■					■					■	
	Source of inspiration				■				■					■			■					■					■	
	Recreation and tourism				■				■					■			■					■					■	
	Traditional use			■					■					■			■						■					

Symbols and numbers: presentation as in Table 1.

Table 4. Expert assessment of direction of effects and relative importance of components of plant diversity on the generation of ecosystem services.

Presentation of cells as Table 1; p<0.00014 (■).

Type	Services	Direction of effects																								
		Number of species					Species evenness					Functional diversity					Spatial turnover					Structural diversity				
		–	1	+	0	?	–	1	+	0	?	–	1	+	0	?	–	1	+	0	?	–	1	+	0	?
Provisioning	Food, fodder, fiber and biofuel intensive production			■																						
	Timber production																					■				
	Firewood production								■															■		
	Diverse products			■					■					■					■					■		
Regulating	Soil fertility			■					■					■										■		
	Plant pests			■					■					■					■					■		
	Resistance to plant invasion			■					■					■					■					■		
	Response of the ecosystem to extreme events			■					■					■					■					■		
	Water availability			■										■										■		
	Climate regulation and air quality													■										■		
Cultural	Scenic beauty			■					■						■				■					■		
	Source of inspiration			■											■				■					■		
	Recreation and tourism			■					■						■				■					■		

Type	Services	Relative importance																							
		Number of species				Species evenness				Species composition				Functional diversity				Spatial turnover				Structural diversity			
		1	2	3	?	1	2	3	?	1	2	3	?	1	2	3	?	1	2	3	?	1	2	3	?
Provisioning	Food, fodder, fiber and biofuel intensive production											■						■							
	Timber production	■				■						■		■				■				■			
	Firewood production					■						■		■				■				■			
	Diverse products			■								■													
Regulating	Soil fertility											■													
	Plant pests			■								■													
	Resistance to plant invasion			■								■													
	Response of the ecosystem to extreme events					■										■									
	Water availability					■																			
	Climate regulation and air quality	■				■																			
Cultural	Scenic beauty					■						■			■									■	
	Source of inspiration					■								■											
	Recreation and tourism					■						■		■											

Traditional use	■	■	■	■	■	■		■			

Symbols and numbers: presentation as in Table 1.

Table 5. Expert assessment on the relative importance of plant diversity with respect to that of abiotic resources and conditions for the generation of ecosystem services. Presentation of cells as Table 1; p<0.00014 (■).

Type	Services	Plant diversity				Resources												Conditions											
						Water availability				Energy availability				Nutrients availability				Soil type				Position within the landscape				Disturbance intensity			
		1	2	3	?	1	2	3	?	1	2	3	?	1	2	3	?	1	2	3	?	1	2	3	?	1	2	3	?
Provisioning	Food, fodder, fiber and biofuel intensive production	■						■				■				■													
	Timber production	■						■				■				■				■									
	Firewood production	■						■				■				■													
	Diverse products			■																									
Regulating	Soil fertility		■													■				■									
	Plant pests			■		■				■								■				■							
	Resistance to plant invasion			■																		■						■	
	Response of the ecosystem to extreme events			■																								■	
	Water availability							■																■					
	Climate regulation and air quality																					■							
Cultural	Scenic beauty			■						■				■				■											
	Source of inspiration			■						■				■				■											
	Recreation and tourism			■				■		■				■				■											
	Traditional use			■						■																			

Symbols and numbers: presentation as in Table 1.

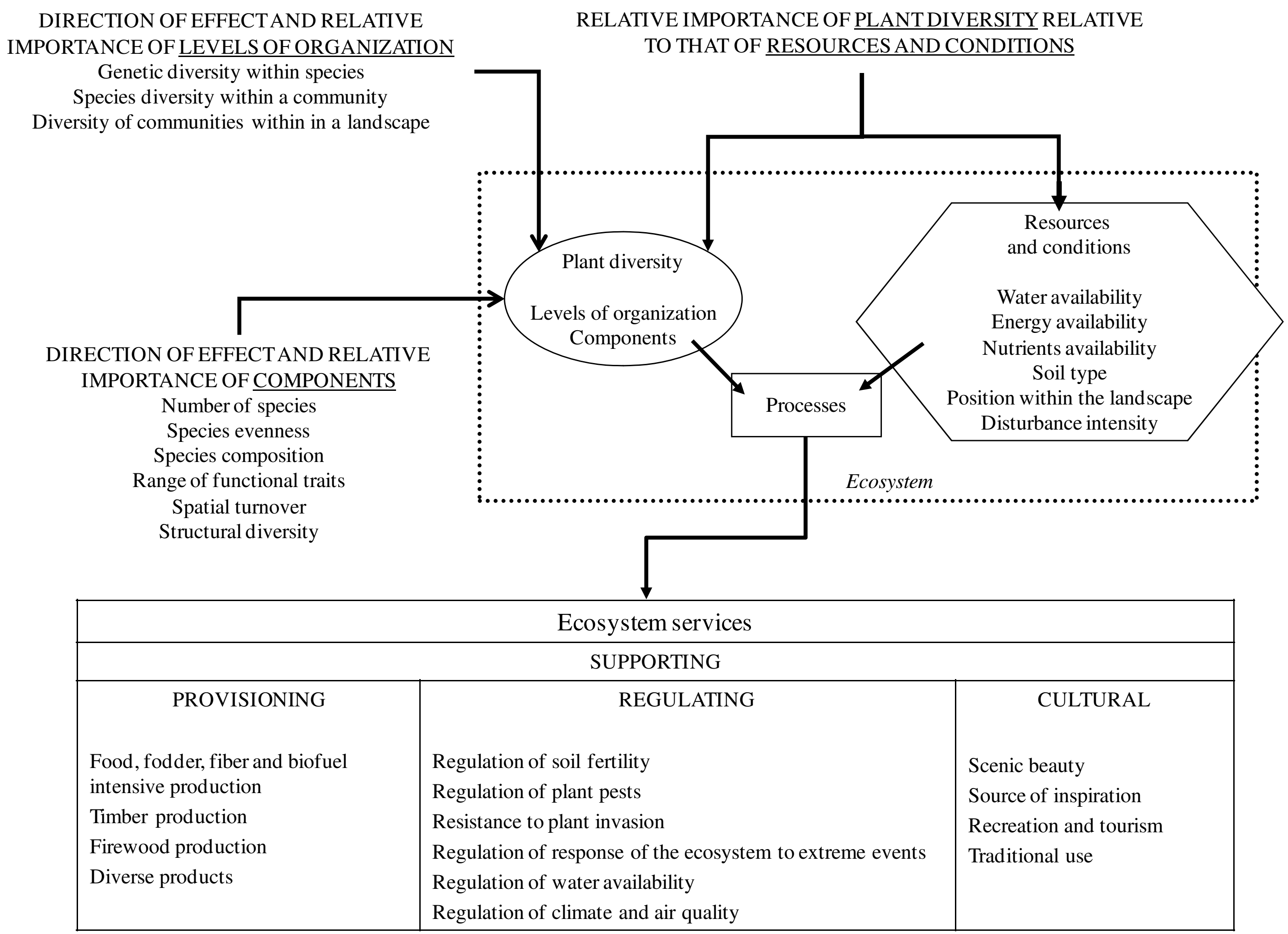

Figure 1. Framework for the design of the survey on plant diversity and the generation of ecosystem services.

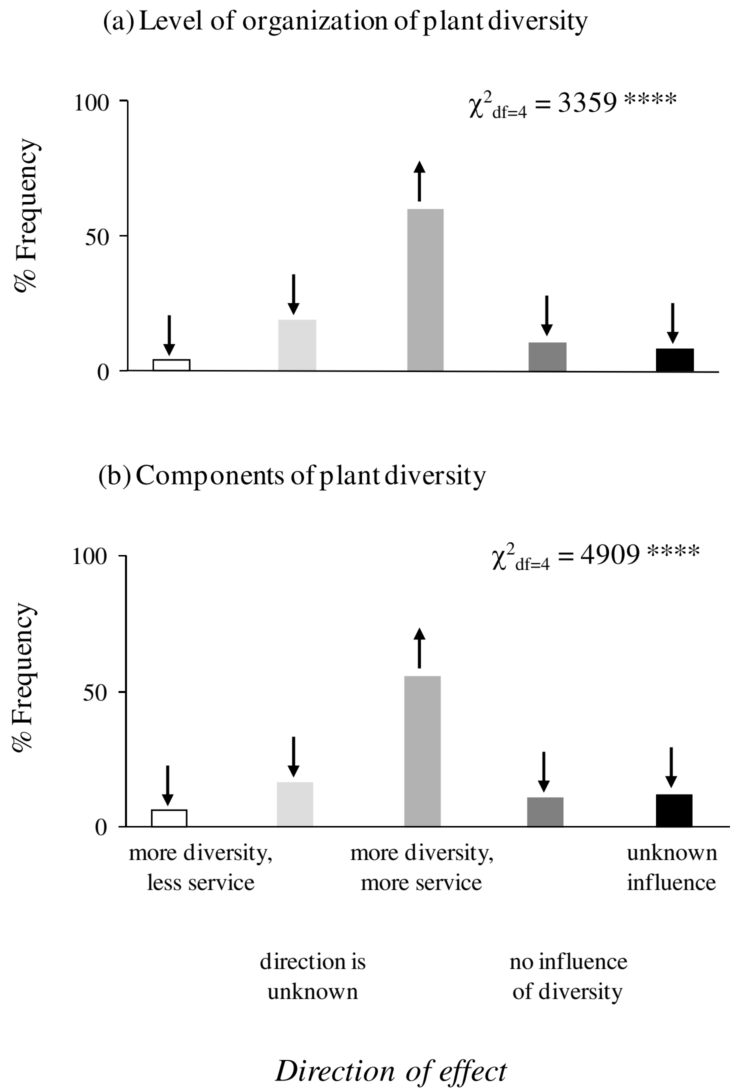

Figure 2. Total frequency of expert assessment on direction of effect of levels of organization and components of plant diversity on the generation of ecosystem services. In (a) the total frequencies of answers for each type of effect were obtained by adding up both all levels of organization and all services; in (b) the total frequencies of answers were obtained by adding up both all components and all services. Arrows indicate that frequencies were significantly higher (↑) or lower (↓) than expected from a null model of equal frequencies of all answers.

Appendix S1. Glossary of terms used in this survey.

The <u>ecosystem services</u>

Food, fodder, fiber and biofuel intensive production: products from plants within human dominated systems (agricultural, pastoral and agro-pastoral systems).

Timber production: solid and fibrous parts of trunks in trees with a diameter at breast height ≥ 30 cm, which are used as construction material or for the manufacturing industry.

Firewood production: wild plant materials used as fuel.

Diverse products: wild plants or their parts extracted from natural to semi-natural ecosystems with present uses as non-timber forest products or future potential uses.

Regulation of soil fertility: regulation of the amount and availability of nutrients (NPK) for the establishment and growth of plants.

Regulation of plant pests: regulation of the populations of herbivores, fungal and microbial pathogens that attack plants in agricultural, pastoral or forestry systems.

Resistance to plant invasion: inhibition of the establishment, growth, survival, and reproduction of invasive species, defined as plants that are established beyond their distribution range.

Regulation of response of the ecosystem to extreme events: regulation of the impacts of an extreme event (e.g. intense rains, strong winds, drought, extremely high or low temperatures, fires and tropical cyclones) on the ecosystem and of its consequences on human settlements within the ecosystem.

Regulation of water availability: regulation of amount, quality and temporal variability of freshwater considering the complex interactions between climate, water cycle components, vegetation and soil characteristics that occur at multiple spatial and temporal scales.

Regulation of climate and air quality: the influence of functional composition of vegetation and size and spatial arrangement of landscape units over large areas, modify albedo, heat absorption, movement of air masses of different temperature and moisture at the local, regional, and global scales.

Scenic beauty: important source of aesthetic pleasure.

Source of inspiration: source of inspiration for artistic, cultural and spirituals expressions.

Recreation and tourism: place where people can rest, relax, refresh and enjoy.

Recreation and tourism: is the incorporation of places or products following in traditional rituals and customs that bond human communities.

The levels of organization of plant diversity

Genetic diversity within species: variation between individuals of the same population in their genetic (and phenotypic) characteristics.

Species diversity within a community: variation of the characteristics of the species that coexist in a same community included the variation between ecotypes and varieties of crops.

Diversity of **communities** within in the landscape: variation in characteristics of the communities (or associations of species) that are found within a same landscape unit.

The components of plant diversity

Number of species: amount of species within a plant community.

Evenness species: similarity in the relative contribution of the species of a community to the relative abundance, relative biomass, or relative cover within a plant community.

Species composition: specific combination of the species or presence/absence of particular species within a plant community.

Functional diversity: expressed as range of variation for different functional traits between groups of species and therefore different effects on the functioning of the ecosystem.

Spatial turnover: changes in the composition of species along space within a plant community.

Structural diversity: variation in plant height, architecture, strata (stratum) quantity, location and position of plants or their parts within a plant community.

The resources and conditions

Water availability: total amount of available water for plants for a given area as rain, snow, hail, fog or dew within a given period time.

Energy availability: total amount of energy used for plants in metabolic activities associated with photosynthesis.

Nutrient availability: amount and availability of inorganic nutrients (NPK), necessary for plant growth.

Soil type: physical and structural characteristics of soil that determine its capacity to support plant development.

Position within the landscape: localization occupied by vegetation unit in the relief (e.g. ridge, slope, piedmont).

Disturbance intensity: intensity (measurement of impact), frequency (number of times it happens for a given time), magnitude (affected area) and duration (time of permanence) of the disturbance.

Appendix S2. Phases of building the survey assessment.

A first version of the survey considered 15 ecosystem services, five levels of organization and six components of plant diversity, and six resources/conditions. This first version was applied to 15 graduate students. As a result of this pilot we reduced the amount of services to reduce fatigue effects during interviews, and deleted aspects that were not relevant at the landscape scale (e.g. biome level of organization). A second version of the survey considered 11 services, five levels of organization and six components of plant diversity, and six resources/conditions.

The second version was applied to 10 researchers at the National University of Mexico. Their suggestions to improve the final version of the survey included further explaining the concepts used in each of the steps of the survey, providing more detailed instructions for completing the tables, and including only resources and conditions with potential importance for generation of services at the landscape scale (e.g. evapotranspiration and temperature are probably not so relevant at the landscape scale).

Appendix S3. Background experts that answered the survey on the relationship between plant diversity and ecosystem services.

Table S1. Categories of background experts. With the exception of years of working with plant diversity or ecosystem processes/services, experts could indicate more than one area of study, type of work and organization, and focus ecosystem in which they work.

Background category	Background subcategory	Percentage of expert who belong to the subcategory
Subject to expertise	Plant diversity	21%
	Population ecology	4%
	Community ecology	49%
	Ecosystem ecology	33%
	Management	23%
	Landscape	8%
	Others	15%
Type of work	Basic research	46%
	Applied research	50%
	Decision maker	4%
Type of organization	Institute	93%
	Environmental NGOs	3%
	Governmental agencies	5%
	Other	1%
Years working with plant diversity or ecosystem processes/services	1-10	33%
	11-20	34%
	21-30	23%
	>31	11%
Focus ecosystem	Tropical rain forest	30%
	Temperate forest	20%
	Tropical dry forest	15%
	Grassland	15%
	Agroecosystem	15%
	Desert	14%
	Savanna	8%
	Shrubland	5%
	Coastal	4%
	Wetland	4%
	Succesional forest	4%
	Cloud forest	3%
	Alpine	1%
	Others	5%

Appendix S4. Direction of effect and relative importance of levels of organization, components of plant diversity, abiotic resources and conditions.

We registered the frequencies of the different types of responses and then addressed the following question:

How do type of service, type of plant diversity attribute, type of abiotic resources and conditions and interactions among these factors explain differences in how frequently experts chose different types of effects and what relative importance they assigned to plant diversity for the generation of services?

We evaluated the significant differences in the frequencies for direction of effects and relative importance of plant diversity, and abiotic resources and conditions on the generation of services with generalized linear models. Significant effects of type of services (e.g. services × direction of effect), of type of plant diversity attribute (e.g. level or organization × direction of effect), of the type of resources and conditions (e.g. resources/conditions × relative importance) and interactions among these factors (e.g. services × level of organization × direction of effect), on the frequencies of the different types of effect or relative importance were identified. All generalized linear models assumed a Poisson distribution and a log link function within S-Plus (Crawley, 2002).

The results showed significant differences in expert assessments were consistently found in the generalized linear model for direction of effect and relative importance of plant diversity, as well as abiotic factors on the generation of services (Table S2). Experts recognized that the direction of effect and relative importance of plant diversity on the generation of services varied among services, between levels of organization and components, and among combinations of particular services and particular plant diversity attributes. Similarly, variation in the frequencies of the relative importance of different abiotic resources and conditions were found among services, among resources/conditions and among combinations of resources/conditions and services.

Table S2. Results of generalized linear models of levels of organization and components of plant diversity as well as abiotic resources and conditions on the generation of ecosystem services.

	Exploratory term	Deviance	Df	p	% Deviance
Levels of organization of plant diversity	Service × Direction of effect	656.6	52	<0.0001	15.3
	Levels of organization × Direction of effect	565.8	8	<0.0001	13.2
	Service × Levels of organization × Direction of effect	235.7	103	<0.0001	5.5
	Service × Relative importance	117.8	39	<0.0001	3.7
	Levels of organization × Relative importance	905.2	6	<0.0001	28.4
	Service × Levels of organization × Relative importance	568.2	76	<0.0001	17.8
Components of plant diversity	Service × Direction of effect	922.0	52	<0.0001	16
	Component × Direction of effect	455.4	20	<0.0001	7.9
	Service × Component × Direction of effect	376.5	260	<0.0001	6.5
	Service × Relative importance	255	39	<0.0001	8.5
	Component × Relative importance	470.9	15	<0.0001	15.6
	Service × Component × Relative importance	424	195	<0.0001	14.1
Resources and conditions	Service × Relative importance	409.4	39	<0.0001	8.3
	Resources/conditions × Relative importance	231.1	18	<0.0001	4.7
	Service × Resources/conditions × Relative importance	29.1	234	<0.0001	26.1

Explanation: Df: degrees of freedom, eg. Service × Effect = (n-1) × (n-1) = (14-1) × (5-1) =52; p value is based on the deviance (Chi-square test)

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Appendix S5. Biases associated with background experts that were found on the frequencies for direction of effects and relative importance of plant diversity on service generation.

Table S3. Biases given by expert´s background. The columns identify the background of experts while rows identify the different sections of the questionnaire. The degree of significance of a χ^2 test to explore for independence of answers with respect to expert characteristics (e.g. five types of relations vs. type of ecosystem).In bold the responses that were significantly more frequent than those expected by null model indicating both the category of expert and the response they prefer; in italic the responses that were significantly less frequent.

Exploratory term in the survey	Background category
Direction of effect of levels of organization of plant diversity	χ^2 = 54.6, P<0.05, df= 12; environmental NGOs **(0)**
	χ^2 = 44.8, P<0.05, df= 12; < 10 years expertise *(1)*
	χ^2 = 205.5, P<0.05, df= 52; agroecosystem **(?)**; wetland **(-)**
Relative importance of levels of organization of plant diversity	χ^2 = 44.8, P<0.05, df= 12; 21 to 30 years expertise **(2)**
	χ^2 = 104.5, P<0.05, df= 39; agroecosystem **(?)**; successional forest **(2)**
Direction of effect of components of plant diversity	χ^2 = 346.9, P<0.05, df= 24; plant diversity **(+)**, *(1)*, *(?)*; population ecology **(?)**; community ecology *(0)*, **(+)**; management **(–)**, *(1)*, **(?)**
	χ^2 = 203.3, P<0.05, df= 12; institute *(0)*; environmental NGOs **(0)**, *(–)*; governmental **(0)**, *(?)*
	χ^2 = 87.8, P<0.05, df= 12; <10 years expertise **(0)**; 11 to 20 years expertise *(0)*; 21 to 30 years expertise **(1)**; > 31 years expertise *(1)*
	χ^2 = 516.6, P<0.05, df= 52; temperate forest *(?)*; tropical dry forest *(?)*; agroecosystem *(+)*, **(?)**; desert *(?)*; savanna **(?)**; coastal vegetation *(0)*, **(+)**, **(?)**; wetland **(-)**; successional forest *(0)*, **(?)**; cloud forest **(?)**
Relative importance of components of plant diversity	χ^2 = 120.3, P<0.05, df= 18; population ecology **(?)**
	χ^2 = 103.8, P<0.05, df= 39; agroecosystem **(?)**
Relative importance of plant diversity with respect to that of resources and conditions	χ^2 = 72.2, P<0.05, df= 39; agroecosystem **(?)**

Symbols and numbers: Effects: (–) the more diversity the less service; (1) there is a diversity effect on the service, but it is not possible to determine its direction or the direction is unknown; (+) the more diversity the more service; (0) no influence of diversity on the generation of the services; (?) unknown whether there is an influence of plant diversity for the generation of services. Relative importance: (1) little importance; (2) intermediate importance; (3) very important; (?) unknown importance.

Appendix S6. Publications found in a search of the ISI Web of Knowledge about relationship between plant diversity and ecosystem services

Table S4.1. Publications found in a search of ISI Web of Science and Biological Abstracts for October 2010 for each component of the survey. A search of the ISI Web of Knowledge (http://www.isiknowledge.com) for papers using the specific search terms (in italic) for each component of the survey as a topic yielded a total number of publications (number in this column) in the last 20 years. These articles are not exhaustive of what has been published but they do allow us to assess the relative amount of research on the different topics. We excluded all articles which did not study ecosystem services. The relevant publications considered only studies which solely provide conceptual work or qualitative assessment about relationship, or any case study in a specified area. Some articles appeared in several categories.

Component survey		Search terms	Total number of publications	Number of publications relevant to this survey
Levels of organization of plant diversity	Genetic	*genetic diversity* and *plant* and *ecosystem services* and *landscape*	3	2
	Species	*species diversity* and *plant* and *ecosystem services* and *landscape*	44	6
	Community	*community diversity* and *plant* and *ecosystem services* and *landscape*	28	2
Components of plant diversity	Number of species	*species number* or *species richness* and *plan*t and *ecosystem services* and *landscap*e	32	1
	Evenness between species	*evenness* or *dominance index* or *Simpson index* and *plant* and *ecosystem services* and *landscape*	2	1

	Composition	*composition* and *plant* and *ecosystem services* and *landscape*	22	2
	Range of functional traits	*functional traits* or *functional diversity* or *functional types* or *functional group* and *plant* and *ecosystem services* and *landscape*	16	4
	Spatial turnover	*spatial turnover* or *beta diversity* and *plant* and *ecosystem services* and *landscape*	3	1
	Structural diversity	*structural diversity* and *plant* and *ecosystem services* and *landscape*	6	1
Resources and conditions	Water availability	*water* and *diversity* and *plant* and *ecosystem services* and *landscape*	7	1
	Energy availability	*energy* and *diversity* and *plant* and *ecosystem services* and *landscape*	6	0
	Nutrient availability	*nutrient* and *diversity* and *plant* and *ecosystem services* and *landscape*	2	0
	Soil type	*soil type* and *diversity* and *plant* and *ecosystem services* and *landscape*	1	0
	Position in the landscape	*relief position* or *ridge* or *slope* or *piedmont* and *diversity* and *plant* and *ecosystem services* and *landscape*	0	0
	Disturbance intensity	*disturbance* and *diversity* and *plant* and *ecosystem services* and *landscape*	14	2
Ecosystem services	Food/fodder/fiber/biofuel intensive production	*diversity* and *plant* and *food* or *fodder* or *fiber* or *biofuel* and *landscape*	110	3
	Timber production	*diversity* and *plant* and *timber* and *landscape*	33	1
	Firewood production	*diversity* and *plant* and *fuel* and *landscape*	13	0
	Diverse products	*diversity* and *plant* and *non-timber forest products* and *landscape*	0	0
	Soil fertility	*diversity* and *plant* and *soil fertility* and *landscape*	38	1
	Plant pests	*diversity* and *plant* and *herbivores* or *fungal* or *microbial pathogen* or *pest* and *landscape*	144	10
	Resistance to plant invasion	*diversity* and *plant* and *invasive species* and *landscape*	101	15
	Response of the ecosystem to extreme events	*diversity* and *plant* and *extreme events* or *hurricane* or *flood* or *fire* or *avalanche* or *natural hazard* or *tropical cyclone* and *landscape*	196	5

Water availability	*diversity* and *plant* and *water amount* or *water quality* or *water temporality* and *landscape*	51	3
Climate regulation and air quality	*diversity* and *plant* and *climate regulation* or *air quality* and *landscape*	7	0
Scenic beauty	*diversity* and *plant* and *scenic beauty* and *landscape*	4	2
Source of inspiration	*diversity* and *plant* and *inspiration* and *landscape*	0	0
Recreation and tourism	*diversity* and *plant* and *recreation* or *tourism* and *landscape*	29	3
Traditional use	*diversity* and *plant* and *traditional use* or *ritual* or *customs* and *landscape*	48	3

Table S4.2. Publications found in a search of ISI Web of Science and Biological Abstracts for October 2010 for plant diversity and resources and conditions for each ecosystem services. Details as Table S3.1.

Type	Ecosystem services	Search terms	Total number of publications	Number of publications relevant to this survey
Provisioning	Food/fodder/fiber /biofuel intensive production	*diversity* and *plant* and *food* or *fodder* or *fiber* or *biofuel* and *landscape* and *water* or *energy* or *nutrient* or *soil type* or *relief position* or *ridge* or *slope* or *piedmont* or *disturbance*	36	0
	Timber production	*diversity* and *plant* and *timber* and *landscape* and *water* or *energy* or *nutrient* or *soil type* or *relief position* or *ridge* or *slope* or *piedmont* or *disturbance*	15	0
	Firewood production	*diversity* and *plant* and *fuel* and *landscape* and *water* or *energy* or *nutrient* or *soil type* or *relief position* or *ridge* or *slope* or *piedmont* or *disturbance*	3	0
	Diverse products	*diversity* and *plant* and *non-timber forest products* and *landscape* and *water* or *energy* or *nutrient* or *soil type* or *relief position* or *ridge* or *slope* or *piedmont*	0	0

		or *disturbance*		
Regulating	Soil fertility	*diversity* and *plant* and *soil fertility* and *landscape* and *water* or *energy* or *nutrient* or *soil type* or *relief position* or *ridge* or *slope* or *piedmont* or *disturbance*	30	1
	Plant pests	*diversity* and *plant* and *herbivores* or *fungal* or *microbial pathogen* or *pest* and *landscape* and *water* or *energy* or *nutrient* or *soil type* or *relief position* or *ridge* or *slope* or *piedmont* or *disturbance*	48	1
	Resistance to plant invasion	*diversity* and *plant* and *invasive species* and *landscape* and *water* or *energy* or *nutrient* or *soil type* or *relief position* or *ridge* or *slope* or *piedmont* or *disturbance*	47	5
	Response of the ecosystem to extreme events	*diversity* and *plant* and *extreme events* or *hurricane* or *flood* or *fire* or *avalanche* or *natural hazard* or *tropical cyclone* and *landscape* and *water* or *energy* or *nutrient* or *soil type* or *relief position* or *ridge* or *slope* or *piedmont* or *disturbance*	119	3
	Water availability	*diversity* and *plant* and *water amount* or *water quality* or *water temporality* and *landscape* and *water* or *energy* or *nutrient* or *soil type* or *relief position* or *ridge* or *slope* or *piedmont* or *disturbance*	52	4
	Climate regulation and air quality	*diversity* and *plant* and *climate regulation* or *air quality* and *landscape* and *water* or *energy* or *nutrient* or *soil type* or *relief position* or *ridge* or *slope* or *piedmont* or *disturbance*	5	1
Cultural	Scenic beauty	*diversity* and *plant* and *scenic beauty* and *landscape* and *water* or *energy* or *nutrient* or *soil type* or *relief position* or *ridge* or *slope* or *piedmont* or *disturbance*	1	0
	Source of inspiration	*diversity* and *plant* and *inspiration* and *landscape* and *water* or *energy* or *nutrient* or *soil type* or *relief position* or *ridge* or *slope* or *piedmont* or *disturbance*	0	0
	Recreation and tourism	*diversity* and *plant* and *recreation* or *tourism* and *landscape* and *water* or *energy* or *nutrient* or *soil type* or *relief position* or *ridge* or *slope* or *piedmont* or *disturbance*	12	1
	Traditional use	*diversity* and *plant* and *traditional use* or *ritual* or *customs* and *landscape* and *water* or *energy* or *nutrient* or *soil type* or *relief position* or *ridge* or *slope* or *piedmont* or *disturbance*	22	5

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